The Societal, Social, and Economic Impacts of the World Weather Research Programme Sydney 2000 Forecast Demonstration Project (WWRP S2000 FDP)

LINDA ANDERSON-BERRY

James Cook University Centre for Disaster Studies, Cairns, Queensland, Australia, and Bureau of Meteorology, Melbourne, Victoria, Australia

TOM KEENAN AND JOHN BALLY

Bureau of Meteorology Research Centre, Melbourne, Victoria, Australia

ROGER PIELKE JR.

University of Colorado, Boulder, Colorado

ROY LEIGH

Risk Frontiers, Macquarie University, North Ryde, New South Wales, Australia

DAVID KING

James Cook University Centre for Disaster Studies, Cairns, Queensland, Australia

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ABSTRACT

The Sydney 2000 (S2000) Forecast Demonstration Project (FDP) was initiated by the World Meteorological Organization (WMO) World Weather Research Programme (WWRP) to enable the world meteorological community to cooperatively demonstrate advanced technologies and methods for accurate and specific short-term weather forecasting (nowcasting). FDP output was developed in support of the Sydney 2000 Olympics and trialed throughout and beyond the Olympic period. As is the case with all WWRP projects, the WWRP S2000 FDP included an assessment of the social, societal, and economic impacts of the project's forecasts. The Impacts Study considered how Bureau of Meteorology (BoM) forecasters employed the enhanced FDP information to produce more ''useful'' nowcasts, and how selected end users accessed, utilized, and acted upon these enhanced forecasts. End users included the Sydney Organizing Committee for the Olympic Games (SOCOG) and a small selection of other BoM clients. With few storms or severe weather events during the 2.5-month trial period the opportunity to fully evaluate the impact of the FDP technologies was limited. Nevertheless, positive social, societal, and economic impacts were clearly indicated and additional potential benefits were identified by users. This paper details the WWRP S2000 FDP environment, discusses the processes and outcomes of the WWRP FDP Impacts Study, and outlines the benefits and implications of this type of research to both the producers and users of weather forecast products.

1. Introduction

The World Meteorological Organization (WMO) World Weather Research Programme (WWRP) initiated the Sydney 2000 (S2000) Forecast Demonstration Project (FDP) in support of the Sydney 2000 Olympics. The 2-yr project included an initial setup phase, preliminary testing, operational trial, and evaluation of component systems. Formal FDP trials were conducted in Sydney, Australia, over a 2.5-month period from 4 September 2000 to 21 November 2000, a period that included the Sydney Olympics and Paralympics. The goal of the WWRP S2000 FDP was ''to demonstrate the capability of modern forecast systems and to quantify the associated benefits in the delivery of a real-time nowcast service.'' To this end, the WWRP S2000 FDP included a largely qualitative and limited quantitative assessment of the social, societal, and economic impacts of the project's forecasts. The Olympic Games is one of a small number of regular large-scale events of international significance where the potential for severe

Corresponding author address: Dr. Linda Anderson-Berry, Weather and Ocean Services Policy Branch, Bureau of Meteorology, GPO Box 1289K, Melbourne VIC 3001, Australia.
E-mail: linda.anderson-berry@bom.gov.au

weather to impact large numbers of people is significant. The S2000 Olympics were held over a 2-week period in September 2000 with the Paralympics extending into early October. This period is during the Australian spring and did not coincide closely with the most frequent ‘‘storm season,’’ which typically extends from November to February. The possibility of severe weather nevertheless existed. Throughout the FDP trial period major weather events were limited but included the following: some severe thunderstorms over the metropolitan and surrounding areas that produced large hail and one tornadic event, a lightning event that resulted in the Sydney Harbour Bridge being struck while tourists were present on exposed sections, and strong winds in the morning and early afternoon on the final day of competition, which impacted Olympic kayaking events.

The WWRP systems were developed in the United States, the United Kingdom, Canada, and Australia, and focused on precipitation forecasting, the initial development of convection, and detection of severe weather phenomena. Individually and collectively these systems provided Australian weather forecasters with new, timely, detailed, and focused weather information not previously available. It was expected that the skills, processes, and technologies developed and demonstrated during the FDP would be transferred throughout the broader meteorological community and would ultimately be available for other large-scale events.

2. Role and structure of the S2000 WWRP FDP

S2000 Olympic weather forecasting issues of concern were the weather-related effects on individual sporting and social events and potential impacts associated with the outdoor exposure of large numbers of people and property. Twenty-one highly skilled weather forecasters were selected from Bureau of Meteorology (BoM) regional offices around Australia to provide and maintain a highly sophisticated Olympic weather forecasting service. They provided 0–48-h forecasts of weather elements at 3-hourly intervals for all Olympic venues throughout the S2000 Olympics and the Paralympics, prepared weather briefings for Olympic organizers twice per day, and issued special forecasts as required in the event of rain, thunderstorm, or strong wind conditions. At sailing venues additional forecast requirements included hourly wind speed and gust forecasts. Short-term forecasts—or nowcasts—were considered to be a particularly important component of the Olympic weather service requirement. During the S2000 Olympics and Paralympics, Olympic forecasters were located at the Sydney Olympics Weather Office in the Sydney Regional Forecasting Centre (RFC), at the Sydney Organizing Committee for the Olympic Games (SOCOG) headquarters, and at the sailing and water sports venues. Aviation support for Air Services Australia and various airlines operating out of Sydney’s airports was provided by the BoM forecasters at the Sydney Airport Meteorological Unit (SAMU) located at Sydney airport. Severe weather nowcasts were undertaken in coordination with BoM staff located at the RFC.

The role of the WWRP S2000 FDP was to support and enhance the BoM weather services. It was not, however, integral to it. The social, societal, and economic impacts evaluation of the WWRP project was therefore not an assessment of the Olympic weather forecasting service per se but rather an evaluation of the add-on support and value the WWRP project provided to forecasters and end users during the trial period.

Throughout the FDP trial period each WWRP system operated 24 h day^{-1} and was supported by the teams of scientists and technicians that developed and maintained the technology. These specialists—referred to as the system champions—formed a core of WWRP expertise within the project and provided a basis for interaction with the BoM staff, acting as a focal point of expertise on their particular system. A WWRP manager (informally referred to as the champion of champions) was rostered daily to monitor the various S2000 systems and interact directly with BoM forecasters to present the consensus WWRP FDP forecast position.

Training of BoM Olympic forecasters on the WWRP systems was considered to be essential for optimal use of WWRP FDP products. This was undertaken by the champions in formal lectures and on a case-by-case basis as required, including real-time situations. Additionally, to facilitate the sharing and transferring of knowledge, skills, and experience throughout the broader meteorological community and to ensure a contribution to the existing (and future) body of knowledge, a formal WMO training workshop was conducted for the benefit of other WMO nations in late October 2000.

Early testing and preliminary evaluation of the FDP trial products indicated that it was impossible for forecasters to effectively use the diverse and unfamiliar WWRP systems in a busy warning environment. Hence, an interface to these systems providing automated guidance from all systems in an integrated fashion was devised. This activity was undertaken by the Bureau of Meteorology Research Centre (BMRC) using a Web-based approach so that forecasters could view summary information from all systems in a common graphical format on any computer with access to a Web browser—including forecasters located remotely. Information was displayed on two screens in a severe weather panel and a precipitation panel, each of which contained six product images—as shown in Fig. 1. Simplified cartoon-type representations of objects were employed to represent storm outputs from the systems such as storm cell locations and forecast tracks.

3. Impacts study methodology

a. Primary research foci

The WWRP S2000 FDP Impacts Study was conceived and designed to address two primary research foci.

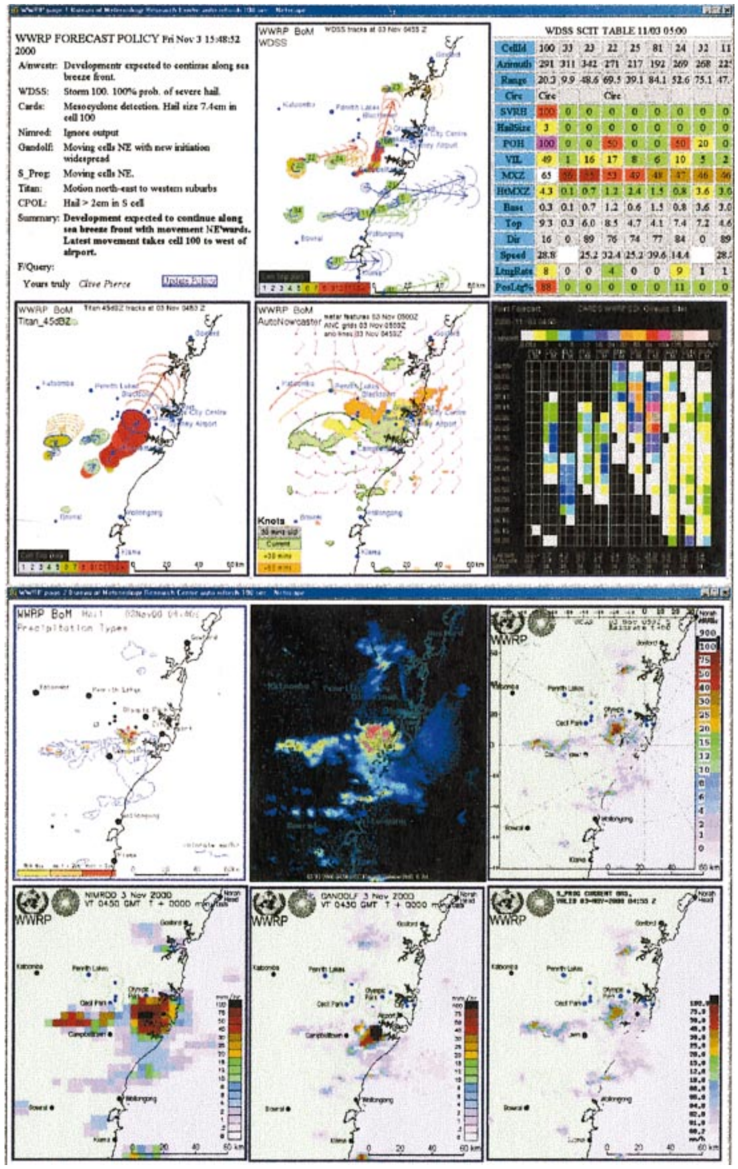

FIG. 1. Example of WWRP S2000 FDP forecaster Web-based guidance products. (a) WWRP summary panel and severe weather guidance that comprises six panels. (top row) System status and WWRP guidance summary with capability for forecaster query, followed by a schematic representation of storm tracks and forecasts color coded by intensity and, in tabular form a cell information summary indicating the presence of severe weather. The next row shows (left to right) major cell tracks and forecasts, derived surface winds with major storm cells and convergent boundaries indicated, and point forecasts of rainfall. (b) WWRP FDP precipitation forecast products. (top row) Polarimetric radar–derived rain-rate analysis with superimposed hail sizes; a standard BoM radar reflectivity and (bottom row) quantitative rainfall forecasts from different FDP systems.

- First, we evaluated how the FDP output was used by forecasters in the production of nowcasts. Focus in this instance was on the BoM forecasters, who drew on information from the WWRP systems.
- Second, we evaluated how the FDP-enhanced nowcasts were accessed and acted upon in the context of broader decision processes. A range of ''secondary users'' that would both directly and indirectly access and utilize the FDP-enhanced forecasts was included. This enabled an investigation of the added value of the technologies in a broader societal context. Additional end users were drawn from both the private and public sectors and were selected on the basis of their varied identified specific weather forecast needs and

on their existing good working relationship with the BoM.[1] They included Air Services Australia, United Airlines, Qantas, Ansett Airlines, New South Wales State Emergency Service, and Bridgeclimb. The Sydney public was also included as an end user and given the opportunity to electronically access one of the WWRP products during the Olympic and Paralympic periods.

b. *Secondary research foci*

Given the unique research opportunities the WWRP S2000 FDP offered, the project was further broadened to enable the consideration of these secondary research questions and issues:

- The implications of lessons learned from S2000 that are relevant to and that may be transferred to similar large-scale public events.
- The documentation of any identifiable change in project effectiveness between the 1996 Atlanta Olympics and S2000 Olympics. This was of interest because the management and decision making processes of the Atlanta Committee for the Olympic Games (ACOG) and SOCOG were very different. SOCOG centralized all processes including the acquisition and redistribution of weather information. ACOG tended to take an opposite approach (Rothfusz et al. 1998). Results may have implications for the effective mode of delivery of weather information.
- The understanding of critical meteorological thresholds for various events/situations. Ultimately an understanding of such information could be included in a discussion of the provision of more appropriate, user-focused weather information products.
- The documentation of how decisions are made in response to specific hazardous weather events with possible implications for enhancing the distribution of future weather information.
- Defining forecast ''quality.'' This is an exciting and growing area of research and involves an evaluation of the perceptions of both producers and users of forecasts as to what inputs and qualities contribute to a ''good'' or a ''bad'' forecast (see Rogell 1972; Murphy and Brown 1983; Murphy 1993; Sink 1995; Pielke 1997; Coleman 1997). This includes consideration of how forecast information is delivered to, and understood by, the end user. The issue of forecast quality also contributes to the broader discussion of how decisions are made on the basis of weather forecast information (Brooks et al. 1997; Pielke and Carbone 2002).

It is acknowledged that most of these are beyond the scope of the current paper. They are mentioned here, however, as a point of interest and to indicate the contribution and value of the WWRP FDP to ongoing longitudinal research projects.

c. *Survey techniques and design*

The Impacts Study was carried out over 18 months during S2000 FDP. Unfortunately, due to early funding constraints, it was not initiated until the FDP was well under way. Consequently the scope of the project was somewhat limited. A range of research and survey techniques, drawing upon both social science and applied meteorological expertise, was employed throughout the study. A series of separate, but related, structured survey questionnaires were developed and administered (via interviews) to system developers, forecasters, and end users or via drop off–mail back and with the application of Web-based approaches, including e-mail.[2] Formal and ad hoc interviews were conducted face to face and by telephone. Unobtrusive observation of forecasters at their workstations was carried out during S2000 and forecasters completed a daily log during the trial period. Both qualitative and quantitative data were collected and subjective forecaster evaluations of both self- and product performance were considered to be an essential component of the impacts evaluation process. Economic assessments were limited and those included in this research have been based solely on the cost estimates provided by the selected end user.

Data supporting the primary research questions are, for the most part, analyzed using qualitative research methods. Simple descriptive statistical analyses are invoked where appropriate.

4. Results

a. *The system champions*

From the outset, system champions were operating under rigid time constraints. FDP systems had to be installed, fine-tuned, and tested fully so that they were operationally robust by the beginning of the trial period. At the same time the system champions had to familiarize themselves with the unique characteristics of Sydney's physical and social environment. The WWRP systems were displayed in a small area adjoining the RFC. The working environment was physically restricted although it was usually easy for champions to communicate freely and observe how each system was performing while closely monitoring their own. Information was continually passed to the Olympic forecasters who were in an adjoining area a few meters away. Interpersonal interactions and communications were observed to be easy and effective.

All champions described the positive and mutually

[1] All ''end users'' invited to participate in the WWRP S2000 FDP were current subscribers to BoM specialist weather services products.

[2] Copies of survey questionnaires can be obtained from the first author.

enhancing professional benefits of their interactions with other systems experts, BoM personnel, the forecasters, and other end users. Overwhelmingly there was an appreciation of the ‘‘willingness of the WWRP participants to do what was required to make the project work.’’ WWRP scientists and system developers frequently commented that they did not usually develop products for direct delivery to the general public. To do so as part of this project was a relatively new experience for many and offered a new challenge. One champion commented that, ‘‘one thing that will come out of this is the experience we have gained learning how to display a lot of information simply—we are not used to this—we do not usually produce displays for the public—just for skilled experts.’’ The effectiveness of system developers working with the users of the nowcasts and gaining a clear understanding of end-user needs was highlighted throughout the project. Communications and interactions with end users were often enlightening; for example, ‘‘I think we were all surprised that during the Olympics there was more interest at the venues in when the rain would stop rather than when it would start. This put renewed interest in forecasting ending.’’ The WWRP training workshop conducted in Sydney toward the end of the trial period gave WWRP scientists the opportunity to share their combined knowledge and experience.

b. Forecasters

Olympic forecasters were a primary focus of the Impacts Study. It was anticipated that the FDP nowcast process could be evaluated in terms of the forecasters' estimates of the perceived benefits (or not) in their individual nowcasting performance. SOCOG's perceptions of the ‘‘quality’’ of the WWRP-enhanced Olympic weather nowcasts and warnings were also considered.

Ideally, participating Olympic forecasters would have been surveyed prior to their exposure to WWRP S2000 FDP to establish a ‘‘baseline.’’ Unfortunately, this was not possible and baseline data relating to forecast processes and perceived forecast quality were therefore drawn from a randomly selected sample of BoM severe weather forecasters from various Australian RFCs. Not surprisingly, these forecasters described a preexisting approach to short-term forecasting that was systematic, had a scientifically based forecasting process, and utilized a combination of available data sources, computer models, and personal communications to make and confirm forecast decisions. With experience, the forecast process tended to become more systematic and less ad hoc or intuitive. Confidence in their abilities to identify any threatening features in data with an acceptable level of accuracy was generally high, although difficulties due to limited data availability, communication delays, and interruptions—particularly from telephone calls—were frequently described as confidence limiting factors. Forecasters generally considered the ‘‘goodness’’ or quality of a forecast to be dependent on its technical correctness. Most considered that they could produce and deliver *better* forecasts with access to more advanced technology; more information; the automation of some products, which would give them more time to study the weather situation; more experience; a better understanding of local conditions; less interruptions; and better relationships with the media. Most also expressed an awareness of the range of forecasting needs among the various users of their products.

Entries in the Olympic forecasters' daily logs indicated that all available data were used to produce Olympic forecasts. The WWRP systems were used variously, but increasingly, as confidence both in and with the products grew. With practice and increased interaction with the system champions, FDP systems appear to have been used effectively, both individually and in combination, for specific forecasting functions. Forecasters were generally confident that they could quickly identify threatening features displayed on the WWRP S2000 FDP screens at their workstations but none used this information in isolation when making forecasting decisions. Forecasters' accounts of interactions with system champions were overwhelmingly described as being positive, mutually beneficial, and instructive and it was common for an Olympic forecaster, a severe weather forecaster, and an FDP champion to be observed clustered together around a screen and involved in a discussion. There was some frustration expressed at the lack of events that forecasters considered would test the performance of the WWRP systems and also their own ability to fully utilize the output.

Forecasters in both the pre– and post–S2000 Olympics surveys were asked to consider and identify any particular characteristics that contribute to ‘‘good’’ and ‘‘bad’’ forecasts. While both groups emphasized a need for accuracy in terms of time and space it is an interesting outcome of this research that the Olympic forecasters generally demonstrated a more acute awareness of, and sensitivity to, client or user needs. This may be a self-fulfilling result of their participation in WWRP S2000 FDP and their exposure to the Impacts Study; it may be a characteristic of this select group of highly skilled and highly motivated professionals; it may have its roots in the individuals' breadth of experience; it may be a combination of these factors; or it may be unrelated to any of these. The reason cannot be confidently determined at this time. However, it is a vital question in terms of forecast and warning communications, and research in this area is ongoing. Olympic forecasters generally considered that the experience of being involved in WWRP S2000 FDP has had a very positive impact on their current and future work performance and levels of job satisfaction, particularly as many considered they had contributed in some (albeit small) way to the product development. A future research priority for follow-on efforts to S2000 should be to document baseline data on forecaster characteristics and perceptions well in advance of the implementation of an FDP.

c. Sydney Organizing Committee for the Olympic Games—SOCOG

Formal interviews were conducted with range of SOCOG personnel, including executive staff, venue managers, events managers, transport organizers, and security officers in the pre-Olympic period. An attempt was made to gain an understanding of SOCOG organizational structures and decision making processes, both at an SOCOG level and in individual sports and events. Activities that were likely to be affected by weather, and any specified weather thresholds, were identified. Any specific instances or situations when a ‘‘nowcast’’ was indicated were identified, so that any quantifiable cost or benefit arising out of any decisions based on the weather information could be evaluated. It was accepted from the outset that a quantitative evaluation may not be possible, but it was expected that a qualitative evaluation would be achievable.

All event and venue managers identified specific weather forecast preferences but very few had any defined official weather thresholds to prompt action. It was clearly stated that while forecasts relating to the onset of adverse weather conditions were important, an accurate indication of when those weather conditions would abate was often considered to be of much greater importance. This finding was unexpected and presented new challenges for the providers of weather services. For Olympic organizers there was enormous pressure to strictly adhere to the official programming of events. Officials stated that events would almost certainly start on time, despite weather forecasts. However, in the event of a weather-related delay during an event there would be an urgent need for accurate nowcasts so that interruption and disruption could be kept to an absolute minimum. SOCOG’s administrative operations were highly centralized. Olympic weather forecasts products were transmitted directly to the Main Operations Centre and from there information was disseminated to events and venue managers via fax, then to operations managers or umpires via mobile phone, radio, and runners. During S2000 and the Paralympics there was very little weather-related disruption to the program. Olympic weather forecasts and warnings were produced with the addition of WWRP products. As the products were not used consistently, or in isolation to other forecasting tools, it was generally not possible to identify any single WWRP-enhanced Olympic weather forecast, on which SOCOG based defensive action, that could be reliably evaluated. At interview, however, several SOCOG officials and forecasters discussed the forecasting of gust fronts during the kayaking event finals on the final day of the Olympics (1 October 2000). Wind conditions were not conducive to racing for much of the day and competition was delayed. By midafternoon there was a very real risk that the competition would not be completed before the end of the games and the closing ceremony. Forecasters, taking full advantage of WWRP output [particularly the wind profiler and the WWRP Auto-nowcaster system described by Mueller et al. (2003)] produced what were described as ‘‘superb’’ forecasts and the competition was finalized with races being completed between gusts. The fact that significant financial costs to SOCOG, Olympic sponsors, and service providers, and personal costs to competitors, were avoided was largely due to the accurate, timely, FDP-enhanced nowcasts that made the completion of the kayaking events possible.

d. New South Wales State Emergency Service—SES

The State Emergency Service (SES) is a largely volunteer emergency and rescue service. Prior to S2000, a range of SES personnel was interviewed to provide a baseline view of weather forecast needs and uptake of currently available services. All confirmed that the majority of all SES ‘‘call outs’’ are triggered by weather—notably storms, flood, flash floods, lightning, hail, and high winds. Most storms were noted to occur in the late afternoon and early evening during the storm season. Storm warnings and special weather alerts issued by the Sydney Regional Office are typically transmitted to the SES state and divisional headquarters simultaneously via fax and on their dedicated Web site. Messages are then communicated down through the organization via phone, fax, and pager. Ideally, weather forecast information should be used to plan deployment of resources (both human and physical) ahead of storm damage in the community. In reality, however, the SES (like most volunteer emergency service organizations worldwide) is a response organization that is not usually activated until calls for assistance commence. Throughout the interviews there was general agreement that the most useful weather/storm information delivered to the SES was details of where the storm impact has already occurred, the intensity of the impact, and, in the event of continuing severe weather, when it will stop. The likely duration of the period between storms was also considered to be vitally important information. It was suggested that high-definition short-term forecasts might support proactive activation thus reducing response time and possibly resulting in less damage to properties. However, the general feeling of personnel interviewed was that the difference would probably be minimal. There was much concern that activation of local units on forecast warnings (as opposed to in response to callouts) may result in ‘‘false alarms’’ and the consequent imposition on volunteers may ultimately result in a decline in their numbers. SES personnel expressed some concern about baseline storm warning information not clearly defining the area, duration, intensity, and track of severe storms. Weather terminology and map symbols (notably wind barbs) were frequently described as being ‘‘confusing.’’ There was general agreement that

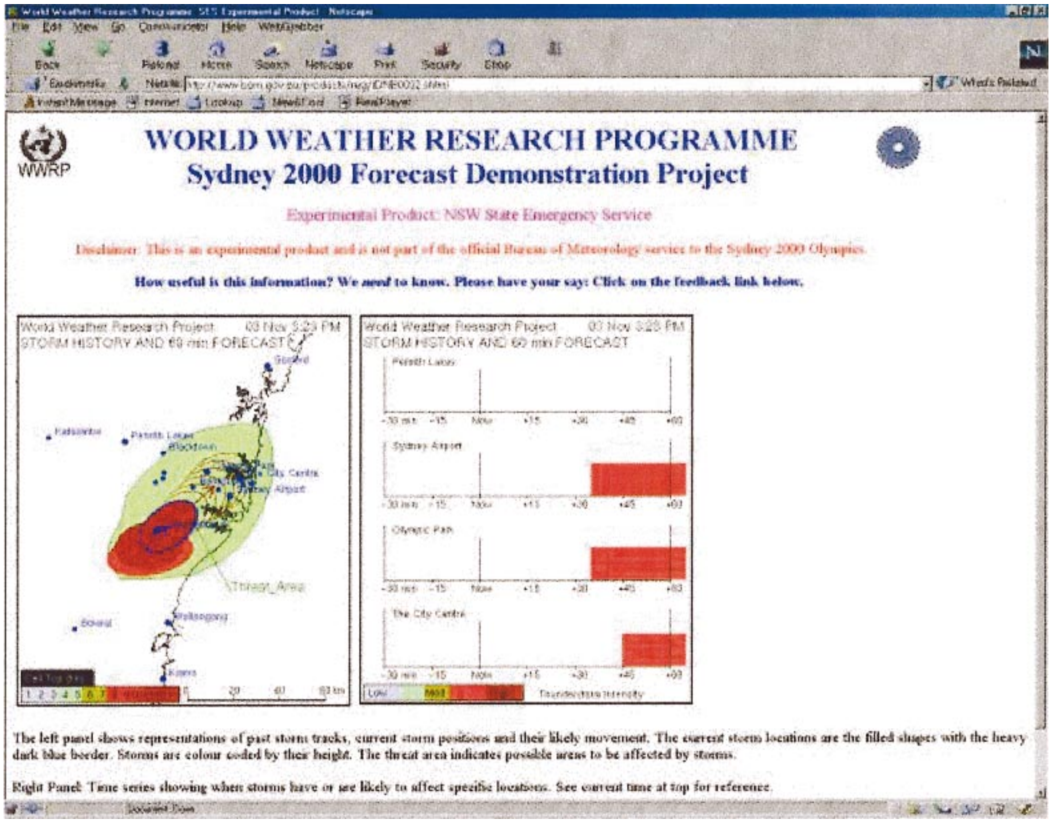

FIG. 2. WWRP S2000 FDP experimental product issued to the New South Wales SES. (left) A cartoon representation of past and predicted storm tracks, color coded by intensity. Threat area for next hour is shaded in green. (right) Times of occurrence of thunderstorm activity (color coded by intensity) at specific locations within the FDP domain.

a useful weather forecast for the SES would ideally be interactive, include graphic and simple text explanations of what has already occurred (and where), and identify expected future impact areas.

In response to SES-identified forecast needs, WWRP system developers designed and produced a graphic and meteogram (shown in Fig. 2) that included an extended storm history together with a text explanation. This new product was considered to have been timely and in an easily understood format. The track and meteogram were considered to have been ''excellent'' and had reportedly contributed to an ''improved quality of response.'' The WWRP products were new to SES personnel and were not used with confidence for proactive decision making. Operations officers stated that the graphics had been useful to support executive decisions, as they were an effective way of demonstrating the areas that were outside the impact area. This was said to have been a ''comfort'' to those who had left homes and properties unattended while responding to emergency calls in other areas. Discussion within the organization relating to WWRP products centered on the potential future utility of the products to the SES. If the storm track forecast information were proven to be consistently reliable, executive officers would consider using it for reconnaissance planning purposes.

e. Air Services Australia

Sydney airport air traffic managers and air traffic controllers are responsible for all aircraft activities in the controlled airspace and on the airport tarmac at Sydney's international and domestic airports. As all weather conditions are of importance to airport operations they routinely access and utilize a suite of publicly and privately produced weather information products. The air traffic managers, as the primary receivers of weather forecasts and data, make decisions relating to runway setup, traffic flow (such as aircraft holding), type of approach (e.g., visual or instrument), potential diversions, and on-route tracking (around a storm). In the event of a thunderstorm, with a the risk of lightning, workplace health and safety regulations require that all ground staff must be withdrawn from exposed sections of the runway and apron until the threat has passed. Sydney airport operations are constrained with a curfew, a legislated maximum number of hourly landing and takeoff opportunities, and by the configuration of the operational runways. Accurate nowcasts are critical for making runway configuration decisions. Immediately prior to the Olympics, new air traffic control radar technology at Sydney airport made dual landings on the parallel runways under conditions of poor visibility possible. This meant that the air traffic system had built considerable resilience to weather-related disruptions into its operations and effectively limited the value of subsequent forecast improvements. As part of the S2000 Olympics effort, Air Services Australia established Olympics Sydney Operations (OSO)—a specialist service responsible for controlling airspace over all Olympic venues and event routes. Location-specific nowcasts were essential for this unit, for example, when making decisions in relation to the number of helicopters that could be allowed over venues and specific events.

Air Services Australia enjoyed the benefits of the WWRP products primarily via forecasts produced by the SAMU forecasters. Air traffic managers and air traffic controllers expressed satisfaction with Olympic and SAMU weather forecasts throughout the very busy S2000 period. It was their perception that forecast accuracy and timeliness throughout the trial period were exceptionally high resulting in a minimum of related delays.

f. Airlines

Throughout the S2000 Olympic period Ansett Australia, Qantas, and United Airlines operated regular services out of Sydney airport. All routinely accessed and utilized the same types of weather information as Air Services Australia, although usually with less direct access to SAMU. Critical fuel load, and landing destination and timing decisions are made based on forecast weather conditions; therefore, it is essential that the best possible weather forecast information be available to airlines within specified time frames. Delays and diversions are estimated to cost an average of 300 Australian dollars ($AUD) per minute or $AUD500 per minute when a diversion to an alternate destination is indicated. United Airlines estimate the cost of a diversion to be approximately $AUD100 000.[3] A delay causing an aircraft to breach curfew restrictions could potentially cost the offending airline in excess of $AUD100 000 in fines.

The airline industry is a BoM client that enjoys access to a range of specifically developed weather forecast products; while generally satisfied with this service, there was a suggestion that a more interactive graphical forecast product was needed. A WWRP aviation product was subsequently designed as part of the WWRP S2000 FDP specifically to address this need. Throughout the FDP trial period WWRP products similar to the SES product shown in Fig. 2 were issued directly to the airlines by fax and via dedicated Web sites on a number of occasions. Although it was not possible to identify any decisions made solely on the basis of WWRP S2000 FDP output the products were reported to have been useful and easy to understand—particularly the wind products. Exposure to the format and detail of WWRP products provoked continuing discussion about potential services that would enhance the safety of the airlines flight operations and a WWRP-designed product is now part of the BoM product set provided routinely to the airlines in Australia. There was overall agreement that the communication and interaction between forecasters and weather service specialists facilitated by the WWRP FDP has enhanced the various working relationships and has improved both the quality of, and satisfaction with, the weather forecast products.

g. Bridgeclimb

Bridgeclimb is a popular Sydney tourist operation that offers guided climbing tours along the arches of the Sydney Harbour Bridge. Groups of up to 20 climbers depart at regular 10–20-min intervals and at any one time up to 100 people are likely to be on the bridge and fully exposed to all weather elements. Weather conditions affect all operations on the bridge. Bridgeclimb staff access weather information from a range of public and private sources including observations from their own weather station on the bridge summit and the observations of climb staff—hair standing on end was noted to be a good test for lightning in the air! The ''technical'' detail in standard BoM forecasts was frequently described as being difficult to interpret and the dearth of simple graphics and text explanations was an often-expressed concern. Maximum wind thresholds for safe climbing on the bridge have been defined and climbing is halted, and a staged evacuation may be initiated, if wind and/or lightning conditions are considered likely to exceed safe limits. Timely, accurate, and readily understood weather forecasts, with regard to all weather elements, including rainfall rates and expected duration of storms, are considered to be essential. Operations are likely to run as far as possible into bad weather because of the ''snowball'' effect on the timetable. In the event of severe weather, climbers on the bridge are immediately moved to ''safe areas;'' a process that takes approximately 15 min. A full evacuation of the bridge requires a warning time of no less than 30 min.

During the trial period specially designed experimental WWRP products were issued to Bridgeclimb on a limited number of occasions. Information was reportedly accessed readily, easily understood, and acted upon quickly. On 29 September 2000, a series of timely storm warnings, including WWRP products, were issued ahead of a severe storm that directly impacted the Sydney Harbour Bridge. The 30–35-min warning was adequate to get people off the bridge to safety. At the time 18 groups were in the climb tour process; 7 of these

[3] These estimates all include fuel, direct and indirect costs of crew, wear and tear of aircraft, and loss of passenger goodwill.

were actually on the bridge. The duration of the storm was 1 h, 10 min. With the benefit of WWRP's storm track forecast graphics, meteogram, and text information, interruption to operations was limited to the cancellation of only seven groups. Bridgeclimb executives believe that on this occasion two groups continued or completed the climb that would probably have been canceled without WWRP enhanced forecasts to support their decision making. On cancellation of a group, overhead costs to Bridgeclimb remain essentially the same (i.e., there is no opportunity to recover lost fixed costs). Direct losses include an average of \$AUD130 per person in lost ticket sales and an additional \$AUD13 per person in lost sales revenue in the souvenir shop. When running at full capacity with groups of 20, this constitutes an average loss of \$AUD2860 for every group that is canceled—that is—every 10 min. Based on these figures it was estimated that, on this occasion, possible loss was reduced by \$AUD5720 in 20 min. Cost estimates provided by Bridgeclimb executive staff did not include any consideration for loss of ''goodwill.''

h. Sydney public

During the S2000 Olympics and Paralympics the WWRP S2000 FDP public weather product was available on the BoM's public Web site, via the Olympic weather information service. The graphic wind and rain forecast, illustrated in Fig. 3, was animated and included a clear text explanation. The Olympic weather site was extremely popular, with a daily average of 20 720 hits recorded throughout the Olympic period. The 4395 visitors to this site that accessed the WWRP FDP experimental products were given a brief explanation about the WWRP products and e-mail feedback was invited and encouraged. The feedback process was somewhat unwieldy and this is likely to have discouraged many potential respondents. All feedback received was overwhelmingly positive and constructive. Potential, rather than actual, utility of the product was more often suggested for both recreational and work-related activities.

5. Discussion

It is often assumed that advances in ''technology'' and a more skillful application of ''the science,'' will automatically translate into ''better'' and therefore more useful products (Pielke 1997). The actual performance or verification measures of the WWRP S2000 FDP are to be considered in a separate study that will measure and test the state of the science, but will not determine the utility of the output products. Verification by itself cannot be assumed to be a complete evaluation. The Impacts Study was an attempt to evaluate the WWRP S2000 FDP qualitatively and somewhat quantitatively through identifiable social, societal, or economic impacts arising from the application of WWRP S2000 FDP output. It aimed to measure how useful (or not) the outcomes of the project were for the people that used the information derived from the various WWRP products to make decisions that affected their livelihoods and well being. Economic impacts are in many ways the easier impacts to identify and quantify, particularly the direct and tangible impacts. Social and societal impacts may be direct and indirect, and both tangible and intangible, and are therefore more often difficult to both identify and quantify. Consequently they are likely to be both underestimated and undervalued. To capture the range and depth of information necessary for the impacts' evaluation both qualitative and quantitative methodologies were invoked. The impacts' assessment, to date, has largely been qualitative in nature and thus many of the significant outcomes have been measured or valued in nonstatistical terms.

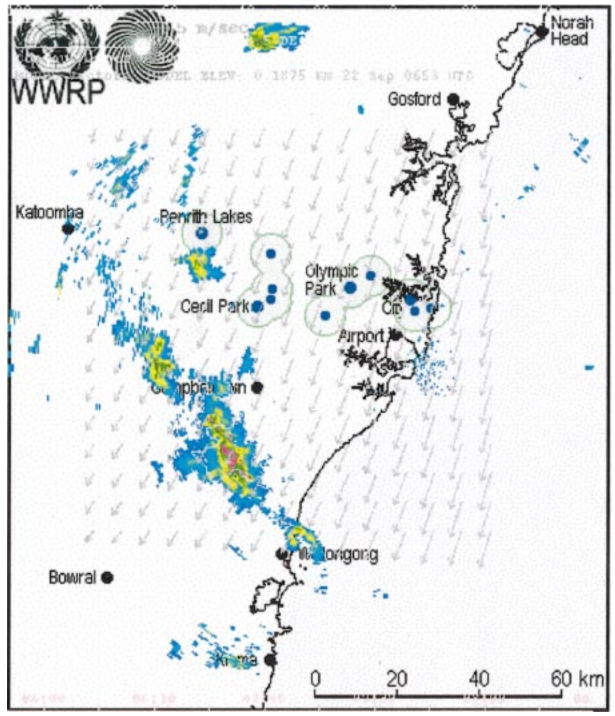

FIG. 3. Example of WWRP S2000 Web product available to the general public showing the current near-surface wind and rainfall distribution [wind is derived from the Auto-nowcaster's radar assimilating 3D model, as described by Mueller et al. (2003)].

Primary FDP issues—Use of WWRP information

The success of the project must in part be measured in terms of whether the products delivered satisfied the weather forecast needs of the user. Integral to this process is identifying and understanding the needs and expectations of the various users then creating or using the technology to satisfy these needs. Identifying user needs was achieved with the early establishment of an interactive and iterative communication strategy between and among the forecast community. This included the WWRP team of international scientists that developed and maintained the systems, the forecasters who creatively and systematically made sense of the range of weather information to produce and deliver weather forecasts, and the community that used weather forecasts to support life and livelihood defensive action decisions.

The synergistic involvement of developers, forecasters, and end users throughout this project was shown to be highly successful. In many cases this was the first time they had directly interacted. The system champions reliably extracted high-resolution data from the various systems—individually and collectively—to input quality nowcast information for the Olympic forecasters and other end users. Their combined effort resulted in products being accessed and employed by forecasters and end users. This process was considered to have contributed positively to the Olympic Games weather forecasting effort, and the system champions expressed immense satisfaction at witnessing the progression of their efforts from scientific inquiry through to a product that was being used in the community.

Direct, regular contact with the system champions fostered the forecasters intense scientific interest in the new technologies and enhanced their skills and confidence in using the state-of-the-art systems. Additionally, being constantly confronted with the need to directly answer user needs sharpened their sensitivity to how weather forecast information is employed and affects the lives of those that use it. In a very real way they were forced to consider how products could be more effectively delivered. In this way, the S2000 FDP offered a paradigm shift in the strategic approach to system development. State-of-the-art science is undoubtedly important but the associated systems need to be viewed as part of a comprehensive approach with user requirements being of primary importance (Pielke and Carbone 2002).

The involvement of the range of selected end users throughout all Sydney-based stages of the WWRP S2000 FDP was both enlightening and productive. Users frequently identified weather information needs and expressed views that challenged assumptions on which weather forecast specialists had typically based decisions on both producing and delivering weather forecast products. Specifically and universally users asked that forecasts, particularly warnings, be presented graphically and with more geographical detail. They suggested that all forecasts should include clear simple text explanations and contain symbols and pictures that are simple enough for people without specialist meteorological training to interpret. It was clear that the users selected to participate in the evaluation project had already identified specific weather forecast needs, and their existing established relationship with the BoM meant that this group was likely to have a raised awareness and understanding of weather forecasting processes and terminology. Nevertheless, all were aware that within their various organizations there were those that lacked this knowledge and who needed to be able to fully understand the weather forecast messages to make decisions critical to the organization. Most stated that a variety of different graphical presentations and site-specific warnings would serve them better. The Impacts Study revealed that, for some users, an accurate picture of the previous path, extent, and severity of storms is just as important, or even more important, than a forecast for the future location of the storm, and that knowing when a storm would end was often as useful as knowing when it would begin. Communication with users identified some of the ways that weather forecast information could be delivered and presented that would be of enhanced benefit. With this knowledge the producers of the WWRP FDP forecasts were able to successfully develop and deliver products throughout the trial period that matched the users needs.

When producing nowcasts all available information, including WWRP output, was utilized, most often in combination. It was difficult therefore for forecasters to reliably weight the relative value of any specific product or WWRP products in the process. It was generally agreed though that as forecasters' confidence both in and with the products increased throughout the trial period, so too did the quality of their Olympic nowcasts. The communication between SOCOG and Olympic weather service providers (including WWRP system developers and Olympic forecasters) contributed to a mutual understanding of forecasting needs and constraints. On at least one occasion, a series of WWRP-enhanced nowcasts allowed SOCOG personnel to complete a competition in difficult weather conditions (see section 4c).

Throughout the trial period WWRP-enhanced forecasts were available in various formats to selected users and the general public. Among all the users of FDP output, social and societal benefits were well demonstrated—albeit often anecdotally. Actual utility of the products was demonstrated among the selected users, and potential utility was suggested by all groups of users, including the general public. Economic benefits were less well demonstrated. However, given the scope of the project and the length of the trial period, this was expected. The clearest economic benefit, in terms of a reduction in potential financial loss that was clearly attributable to the WWRP FDP–enhanced nowcasts, was demonstrated with Bridgeclimb. Air Services Australia, the airlines, and the SES were all able to identify many potential opportunities for cost saving and loss reduction when making decisions with the benefit of high-definition nowcasts. The SES described many actual and potential societal benefits at both an organizational level and to individual volunteers. The general public that accessed information on the BoM's public Web site viewed the product with interest, and also identified potential uses and benefits. WWRP products were described as being ''experimental'' and as such public confidence in the output was likely to be cautious.

6. Conclusions

WWRP S2000 FDP output and nowcasts were evaluated throughout a relatively short period that included and extended beyond the S2000 Olympics. With few severe weather events during the trial period, opportunities to explore the full potential of the products were limited. Nevertheless, positive *actual* and *potential* social, societal, and economic benefits of the WWRP products were clearly demonstrated, primarily through qualitative research methods. Future efforts along these lines should strive for a greater ability to quantify results, particularly through the systematic collection of baseline data on both forecaster and user-decision processes.

Time and experience with the WWRP products was a significant issue for both the Olympic forecasters and the selected end users. Significant training and experience with the products by both groups is an essential prerequisite for the efficient use of the products and confidence in the output. The duration of this project was too short for sufficient training and practice with the products.

Throughout the S2000 Olympics, nowcasting was not the primary issue facing forecasters, mainly because of the lack of severe weather conditions. The development of 3-hourly forecasts out to 24 h occupied much of the Olympic forecasters' time and energy. It was unfortunate that there were no specific NWP systems and guidance on which forecasts on that timescale could be based in the FDP (although they were originally to have been included in the FDP). Such systems, together with provision for adequate training, should be included in any similar future projects. Throughout this study, the benefits of interactive development of products has been highlighted. The operational testing of new weather forecasting products throughout the development stage should therefore be strongly encouraged.

Consultation with the end users throughout all phases of the WWRP FDP has been demonstrated to have a positive impact on both the producers and users of weather forecast products. An effective consultation process should be ''built in'' to future similar projects. Ultimately this will result in an increased ability of the public to use weather forecast products and therefore ''better'' weather-related decisions being made.

This investigation has clearly demonstrated that when operationally tested, the WWRP products contributed to what was perceived to be an improved nowcast service, and made a positive contribution to the Olympic weather service (and in all other instances where they were utilized). Through the process of assessing the impacts of the WWRP FDP state-of-the-art weather forecasting technologies, the WWRP has moved toward developing a better understanding of the societal uses of weather information and short-term forecasts. The Impacts Study has been experimental and prototypical. One important set of lessons from the study refer to how to improve future impacts research associated with the WWRP. This study has provided a framework and baseline for future investigations into the impacts of weather forecast products and it has begun to provide the producers of weather forecasts with an understanding of the societal uses of weather information and short-term weather forecasts.

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